

HabEx



Technology Maturity for the HabEx Observatory Concept

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	Number of Gaps		
	TRL 3	TRL 4	TRL 5
Expected 2019	1	7	6
Expected 2023	0	3	11



Inner working angle (IWA)

124,000 km separation

Telescope aperture diameter 4 m



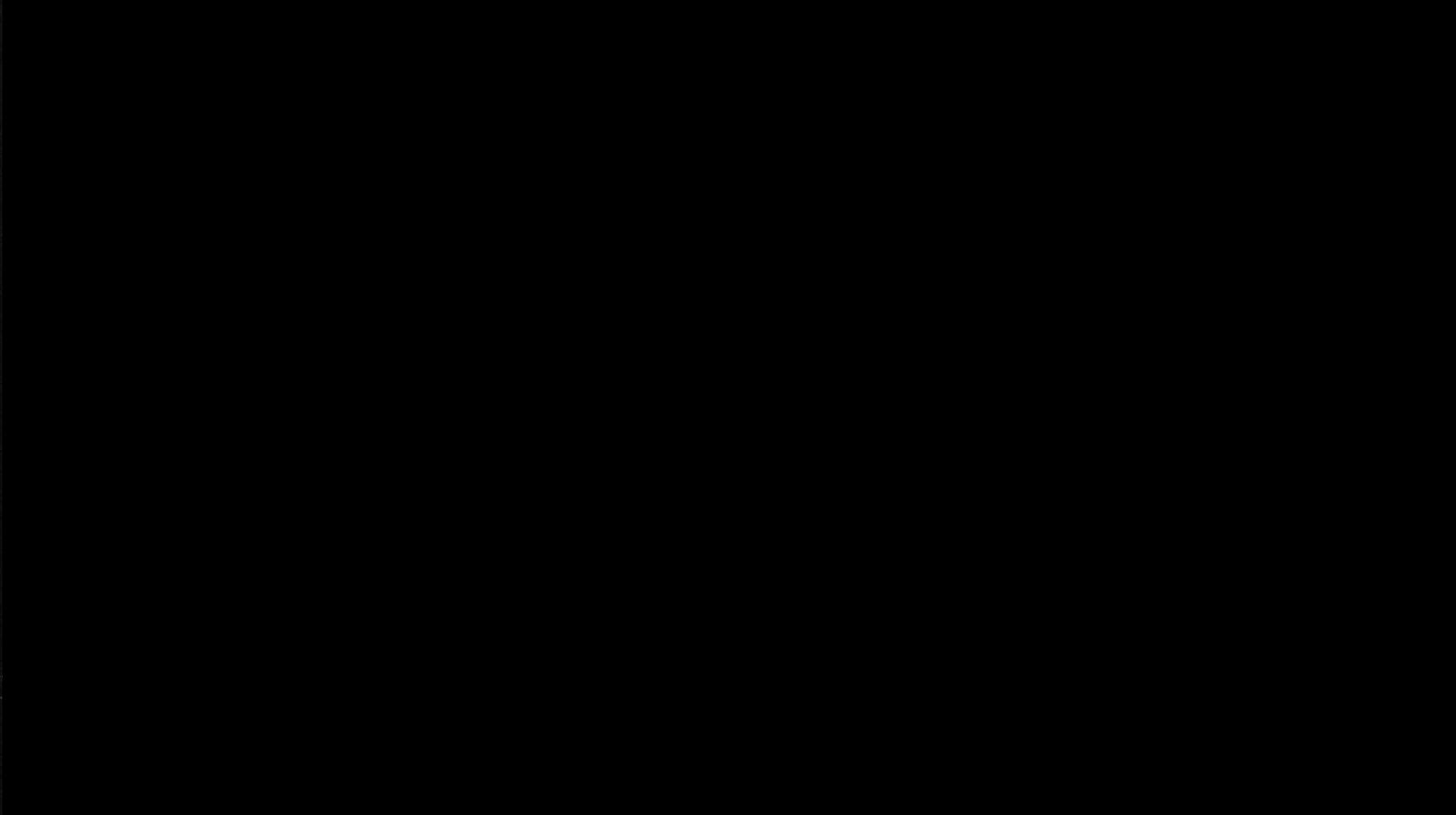
Starshade diameter 72 m



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Starshade Deployment



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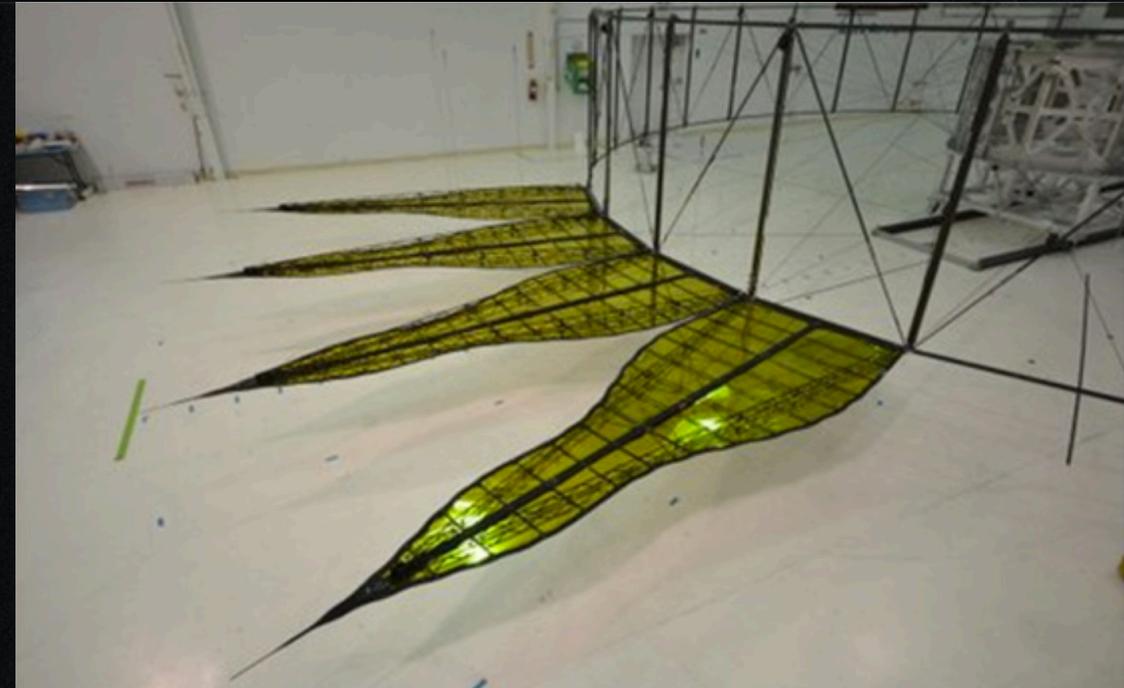
Truss Deployment Test

Starshade Deployment
Technology Demo

August 2013



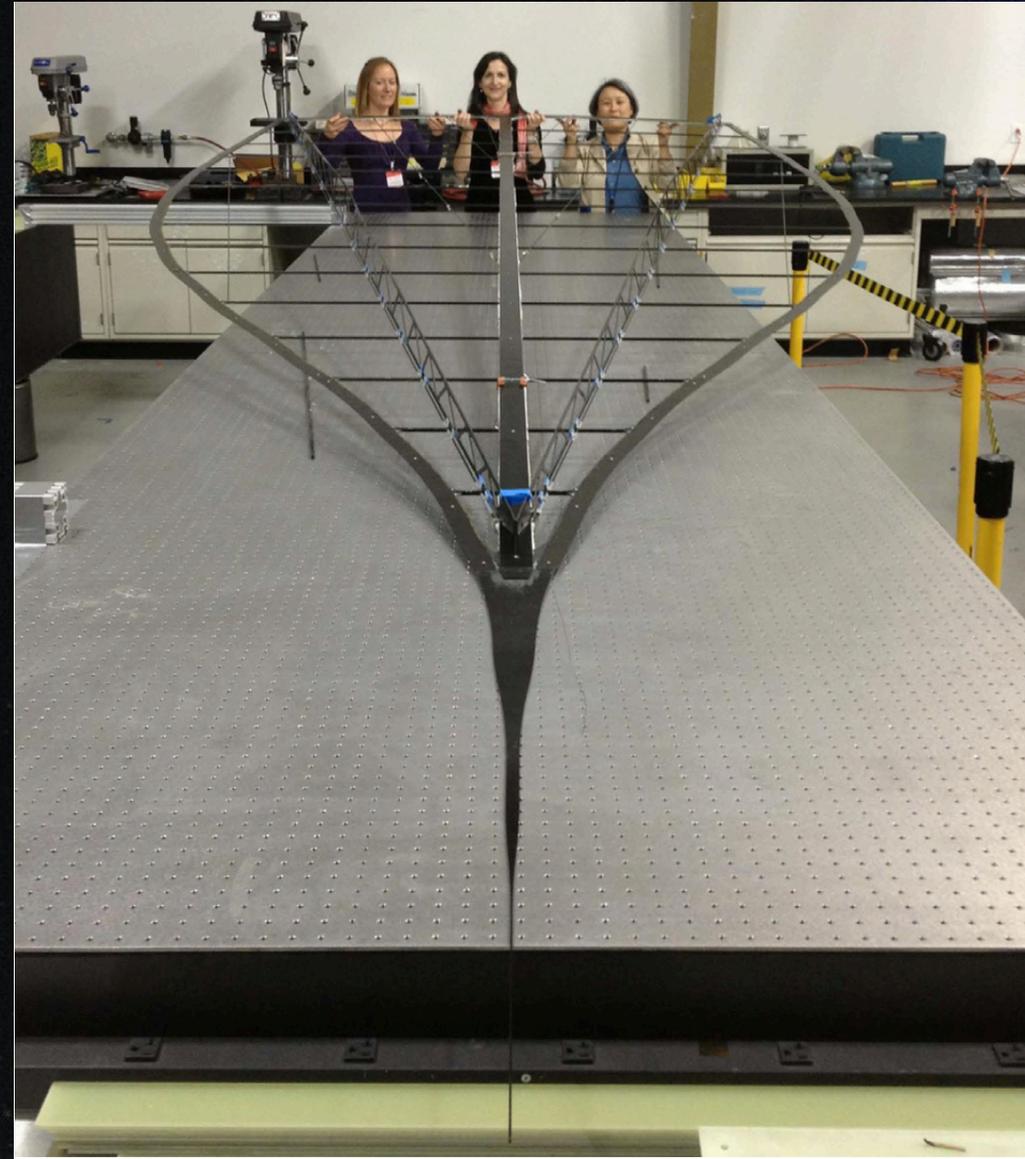
- Starshade tolerances scale linearly
- SOA
 - 12 m flight-like truss
 - Petal deployment tolerance <0.15 mm
- Requirement for 20 m truss
 - ± 0.5 mm (3σ) bias
 - ± 1.5 mm (3σ) stability
 - In operational environment
- Path
 - S5 5m truss half-scale demo planned for 10 m truss
 - HabEx 52m starshade requires 10m half-scale demo truss





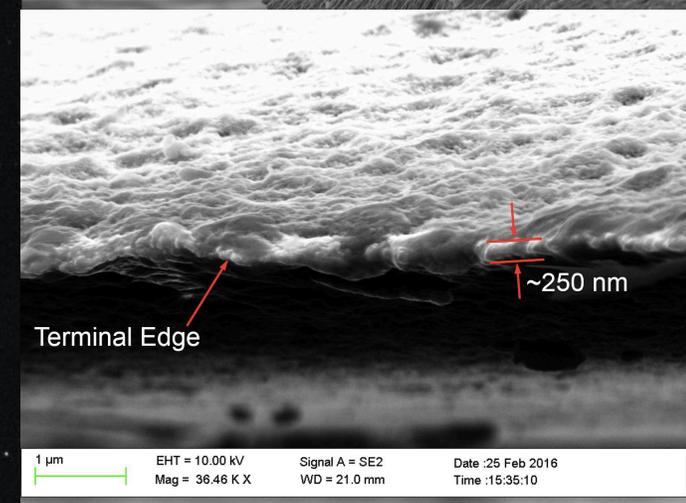
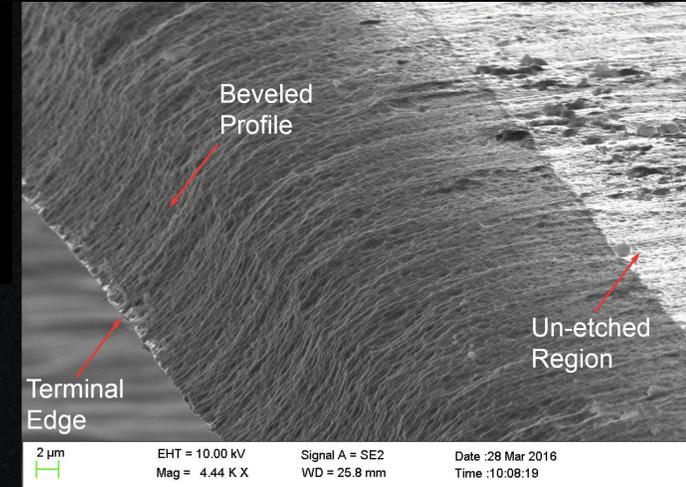
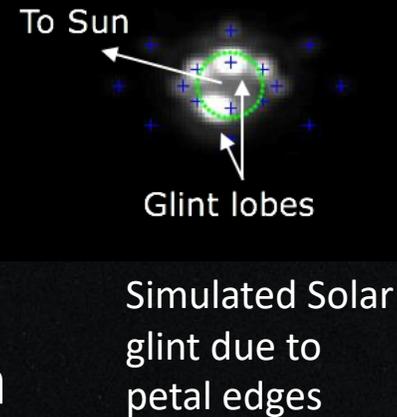
Petal shape and stability.

- SOA
 - 6m prototype petal manufactured to <100 μm tolerance
- Requirement for 16m long, 2.6 m wide petal
 - Shape manufacture to ± 115 μm (3σ)
 - Deployed shape to $< \pm 230$ μm (3σ)
 - Stability (thermal)
 - Disk to petal strain < 30 ppm
 - 1-5 cycle petal width < 20 ppm
- Path
 - S5 4 m long, 1.5 m demo petal for S5 applies to HabEx (stability driven by width)





- SOA
 - Metal edges (coupons) meet all specs but in-plane shape tolerance
- Requirement
 - Petal-edge in-plane shape tolerance 40 μm
 - Solar glint at 25 Vmag in two main lobes
- Path
 - S5 to demonstrate performance at edge segment level
 - Sufficient demonstration for HabEx



SEM images of the beveled edge and terminal edge



- SOA

- Out-of-band sensing of pupil plane images show structure in the low-contrast starshade shadow
- Simulations show ample star flux for control loop and < 0.15 cm lateral displacement (0.01 pixel star positions)

- Requirements

- Demonstrate sensing lateral errors to 0.20 m accuracy, ≤ 1 mas bearing angle
- Demonstrate control algorithms to scaled lateral errors ≤ 1 m

- Path

- S5 testbed demonstration is sufficient for HabEx TRL5 certification expected Feb 2019

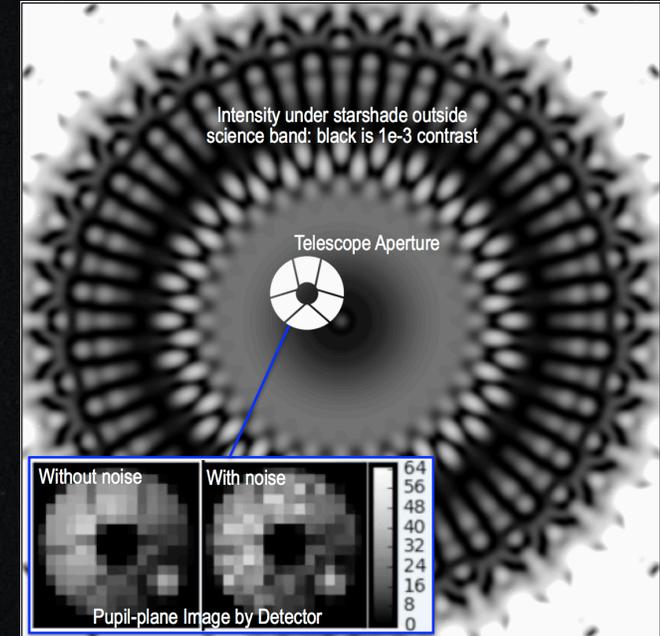
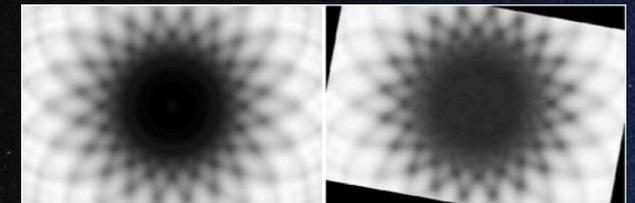


Illustration of lateral sensing using pupil-plane image matching



Preliminary results
Simulation Testbed



Optical Performance and Model Validation

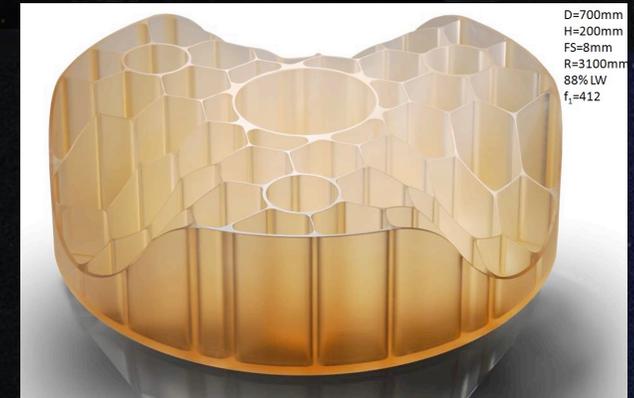
- SOA
 - $6E-6$ suppression in pupil plane at Fresnel No. 15, broadband
 - $6.6e-9$ suppression in pupil plane, $4.3e-11$ average contrast in focal plane at Fresnel No. 13, monochromatic
- Requirements
 - Experimentally validated models
 - with suppression $<1E-8$, F1.0 between 5 and 40 (broadband)
 - Traceable to $1E-10$ contrast system performance
- Path
 - S5 testbed at Princeton expected TRL 5 2019 is sufficient for HabEx



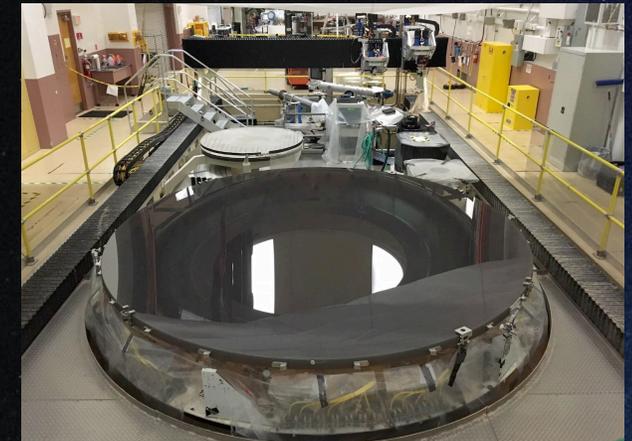
S5's starshade model validation testbed at Princeton.



- SLS allows for moderate lightweighting
- Microthrusters allow for low first frequency
- SOA
 - 4.2m DKIST primary mirror by Schott, UA (2nm surface roughness)
 - 4m ELT M2 by Schott
 - Zerodur CTE homogeneity 10 ppb/K
 - Lightweight cell 340 mm deep, 2mm wall
- Requirements
 - Wavefront thermal stability ~ 1 nm over 100s of seconds
 - First mode > 60 Hz
- Path
 - 4m demonstrator for TRL 5



SCHOTT 700 mm diameter and 200 mm high Zerodur® with 2 mm machined walls, and contouring of the back.



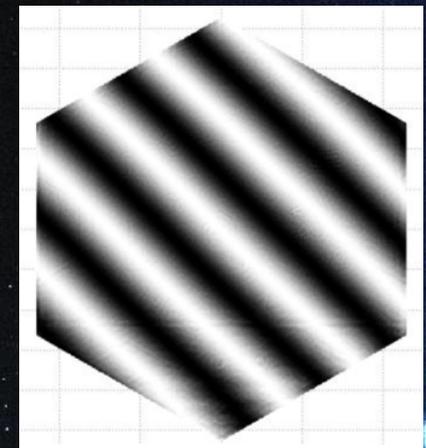
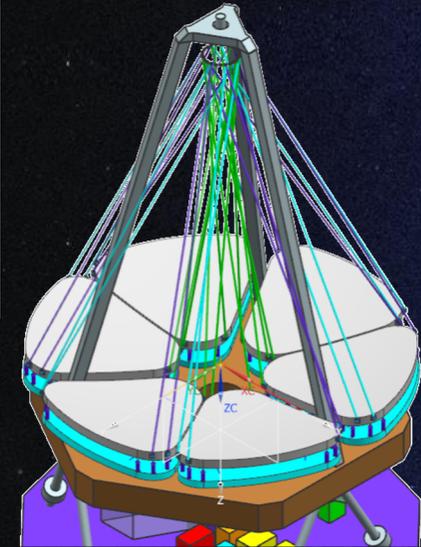
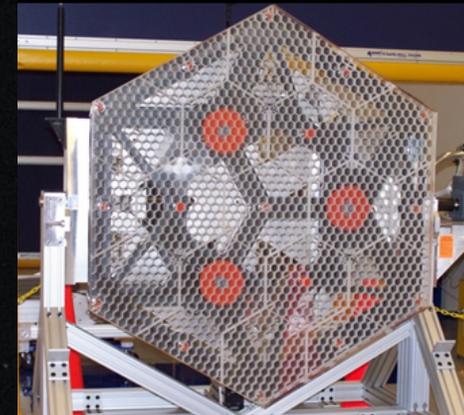
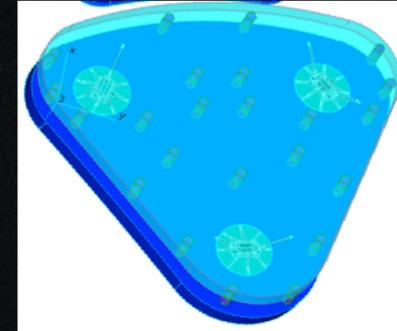
4.2 m Daniel K. Inouye Solar Telescope primary mirror

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3.2m Starshade Only option

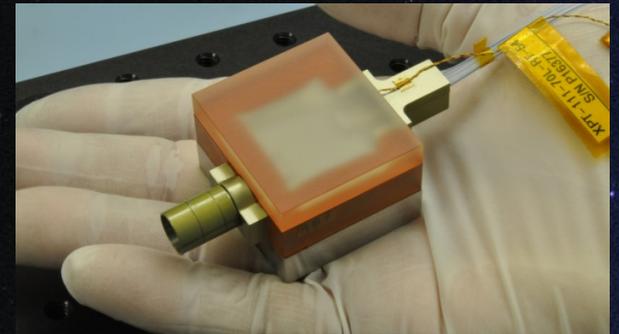
- Starshade only option requires looser WFE
- SOA
 - ULE demonstrator mirror
 - low mass: 10 kg/m²
 - 15 nm RMS WFE stand-alone, with backouts
 - 8 nm WFE RMS post-actuation predicted
- Requirements
 - 34 kg/m² CBE for Falcon H or Delta IV H
 - 18 nm RMS WFE primary mirror, 10 nm RMS stability
- Enhancing developments:
 - Reduce ROC-matching errors
 - Improve 0-g figure prediction
 - 6DOF RB actuation from 1 nm to 10 cm without launch locks





Laser Metrology

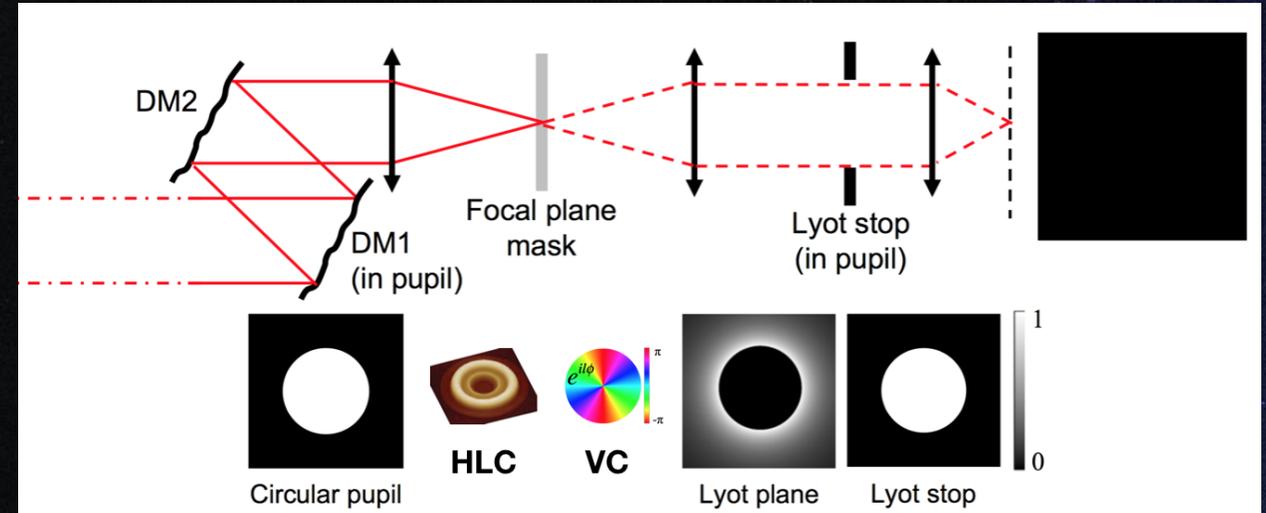
- SOA
 - Laser: Nd:YAG ring laser and modulator on LISA Pathfinder, Grace Follow-On
 - Thermally stabilized Planar Lightwave Circuit fully tested
- Requirements
 - Sense at 1 kHz BW
 - Uncorrelated per gauge error of 0.1nm
- Path
 - At TRL 5 for HabEx



PLC beam launcher



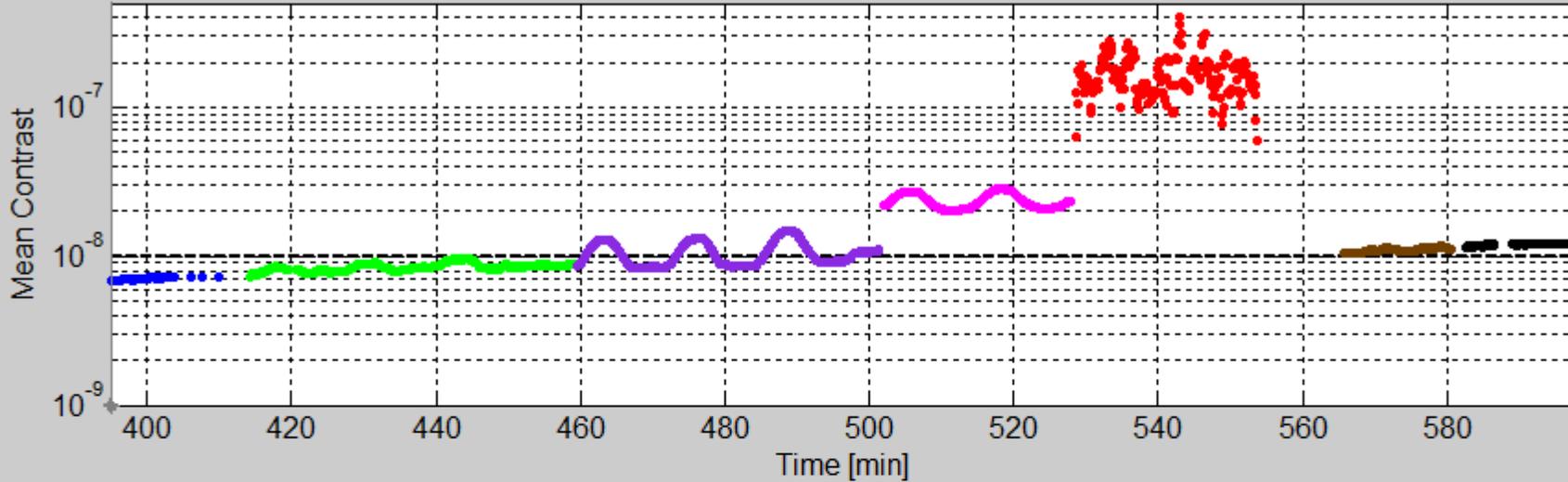
- Requires 10^{-10} raw contrast from 2.4 to 32 λ/D for 20% bandwidth
- SOA
 - VVC $5E-10$ monochromatic,
 - 3-8 I/D, 2-7 λ/D
 - $1E-8$ 10% BW
 - HLC linear mask
 - $6E-10$, 10% BW, 3-16 λ/D
- Requirement
 - $1E-10$ raw contrast, 20% BW,
 - $1E-11$ contrast stability
 - IWA = 2.4 λ/D
 - Coronagraph throughput $\geq 10\%$
 - Dual polarization operation
- Path
 - ExEP Decadal Studies Testbed seeks to show $1E-10$ raw contrast with VVC in static environment by 2019



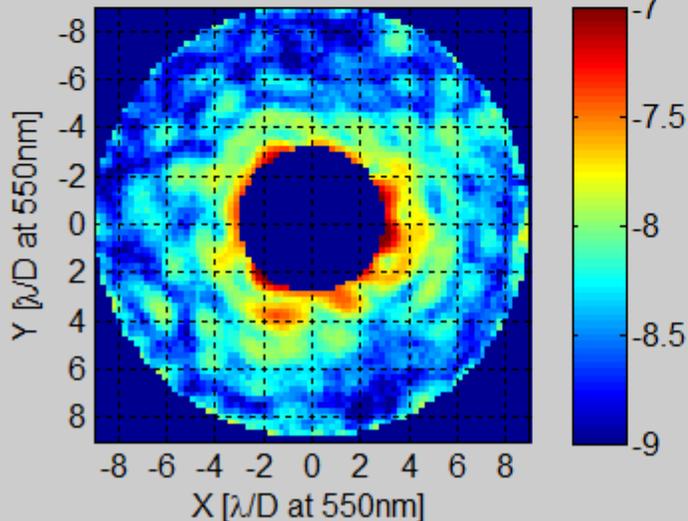
The ExEP Decadal Studies Testbed (DST) strives to achieve 10^{-10} raw contrast for an unobscured aperture.



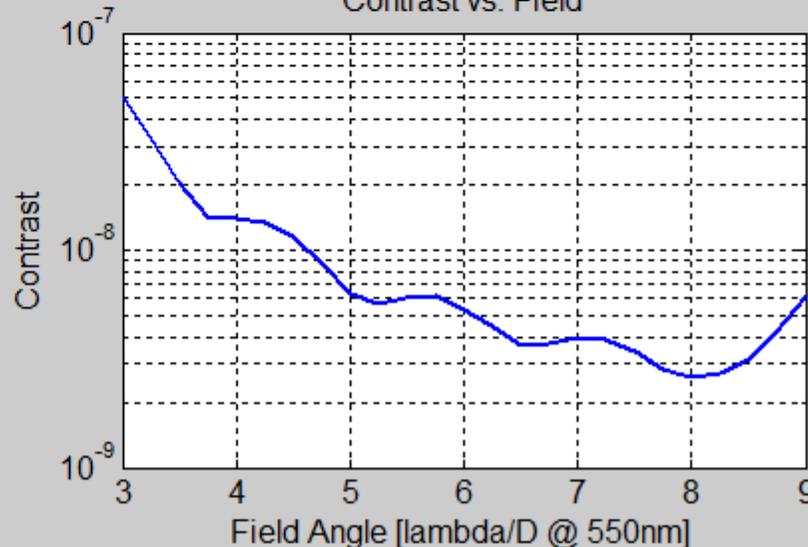
Timeline: Ambient environment



Log Contrast



Contrast vs. Field



Low Order Wavefront Sensing and Control (LOWFS/C) WFIRST testbed

- Injected
 - 14 mas tip/tilt drift + CBE jitter 600 rpm wheel speed
 - +/- 0.5 nm focus sinusoid
- Senses:
 - LoS tip/tilt to 0.2 mas
 - low order mode to 12 pm rms

• The HabEx jitter environment is much more benign due to microthrusters.

- **Path**
- Demonstrate LOWFS/C in full coronagraph testbed with WFIRST CGI like progression



Microthrusters

- SOA
 - Colloidal (CMT): 5-30 μN thrust, 0.1 μN resolution
 - 100 days on ESA/NASA LISA Pathfinder
 - Cold Gas: 1mN max thrust, 0.1 μN resolution
 - 4 years on orbit operations on ESA Gaia
 - *May be on Euclid*
- Requirement
 - Thrust capability of 0.35 mN
 - Operating life of 5 years
- Path:
 - PCOS maturing TRL7 CMT to TRL6 for ESA-led LISA mission
 - Trade Colloidal with cold gas microthrusters
 - Trade: active isolation + RCS with monoprop + microthrusters



A single cluster of four Busek Co. CMTs integrated on the LISA Pathfinder Spacecraft just prior to launch.



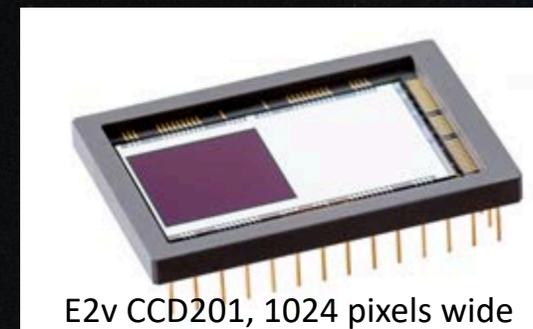
- Boston Micromachines Corp (BMC) Deformable Mirrors (DMs)
 - 0.4 mm pitch
 - Micro Electrical Mechanical System (MEMS)
 - 64 x 64 actuators (4096 actuators)
- Under test in the DST
- Environmental testing in progress (TDEM)
- Phase 2 SBIR to improve residual WFE



BMC 64x64 DM

Image courtesy BMC

- Visible detectors are EM-CCDs
 - CCD201: 1024 pixels for cameras
 - CCD282: 2048 pixels for coro. IFS
 - CCD282: 4096 pixels for Starshade IFS
- WFIRST-CGI lab results for dark current meet HabEx requirements
- WFIRST-CGI EMCCD requirements meet HabEx needs



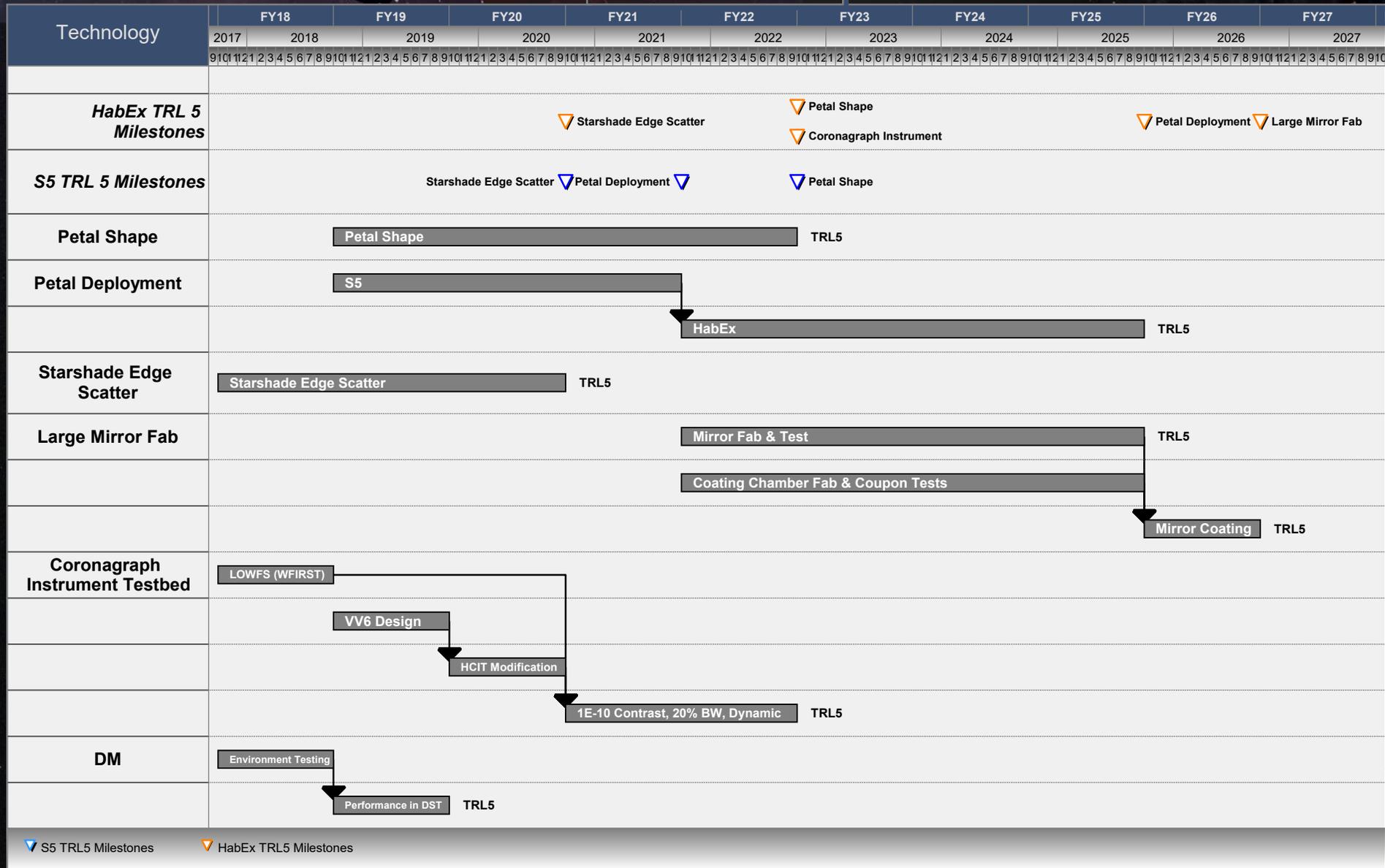
E2v CCD201, 1024 pixels wide

Image courtesy e2v



Enhancing Technologies

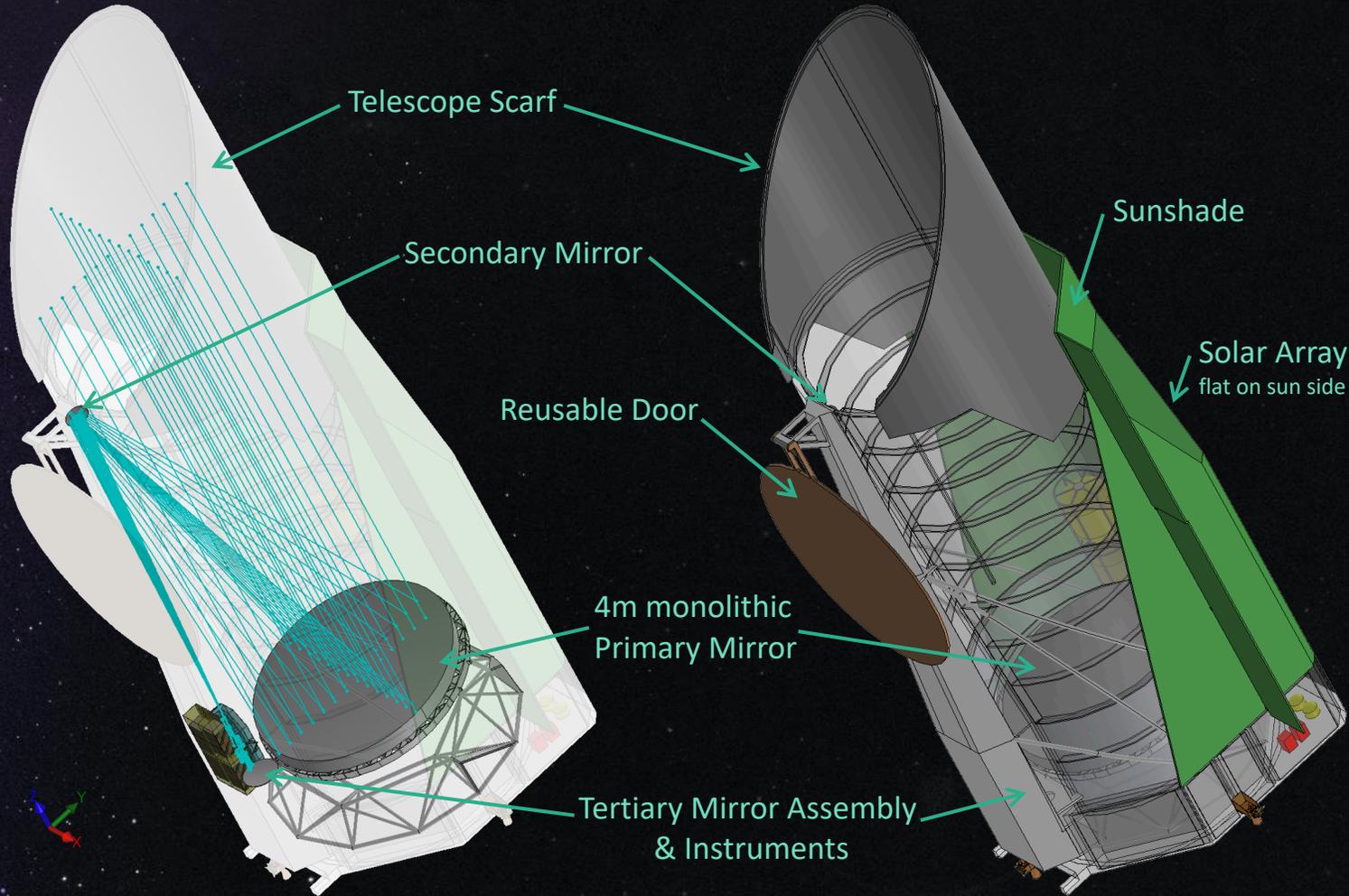
- UV Microchannel Plate Detector
- SOA (TRL 4)
 - dark current $\leq 0.1-1$ counts/cm²/s with ALD borosilicate plates
 - QE 44% 115-180 nm with alkali photocathode
- Requirement
 - Dark current < 0.001 e-/pix/s [173.6 counts/cm/s]
- Path
 - Components integrated into single MCP
 - Adopt if mature in time
- Far-UV Enhanced coatings for 100 nm cutoff
- SOA (TRL 3)
 - Al+LiF+AlF₃ proof of concept show 3 year stability
- Requirement
 - Operational life > 10 years
- Path
 - Adopt if mature in time



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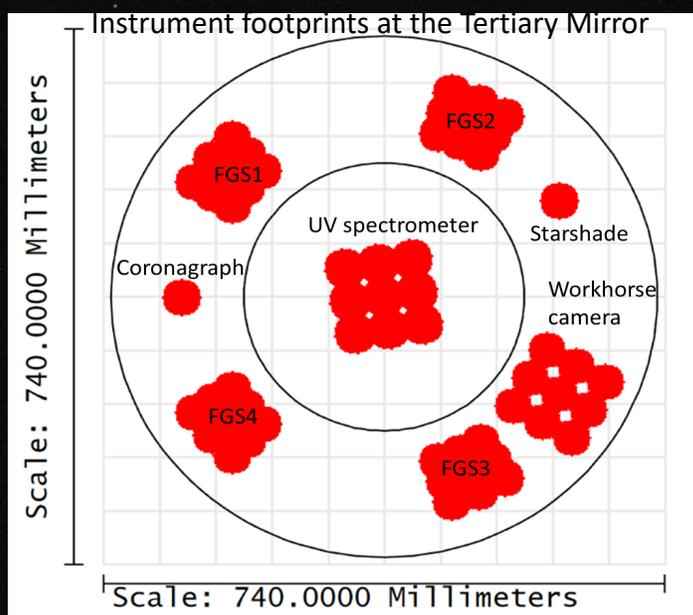
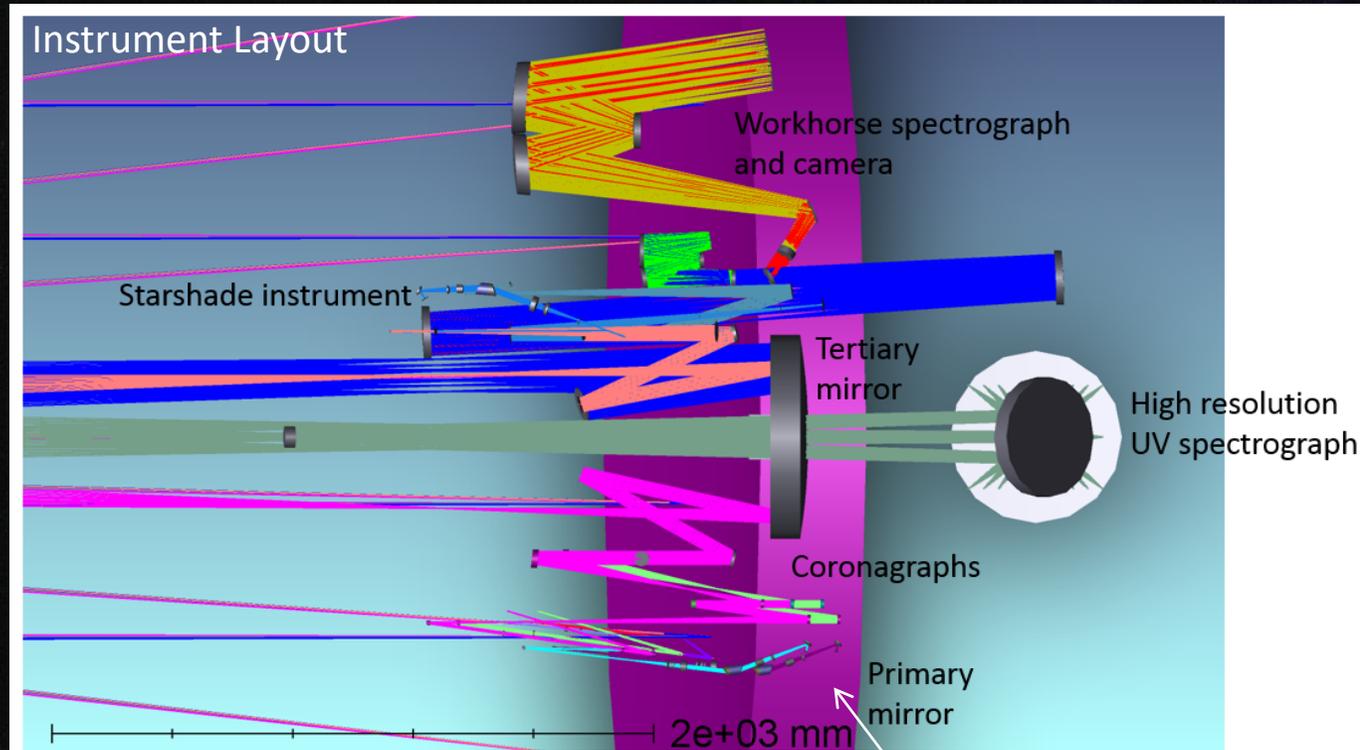
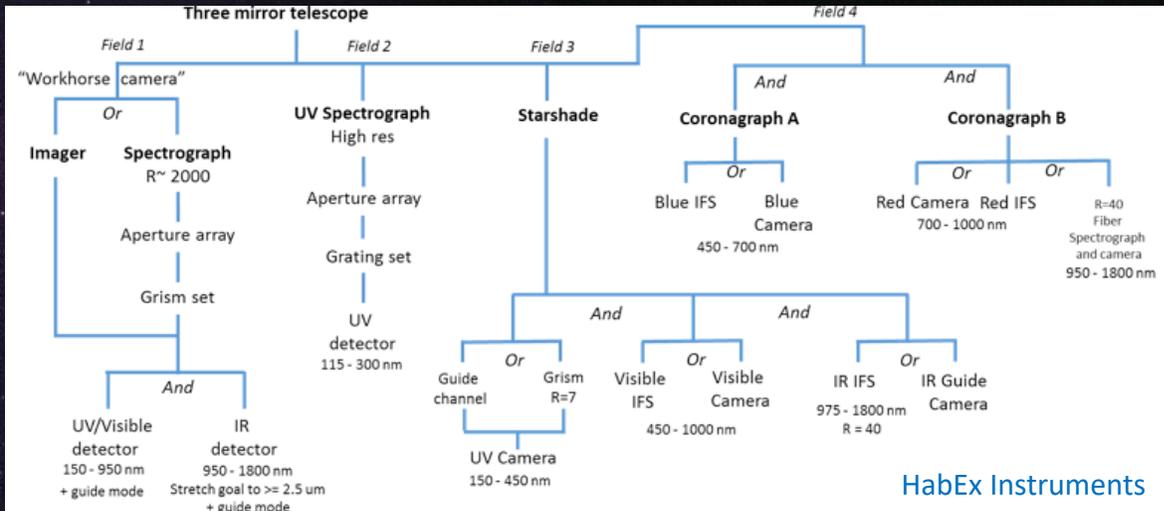
BACKUP

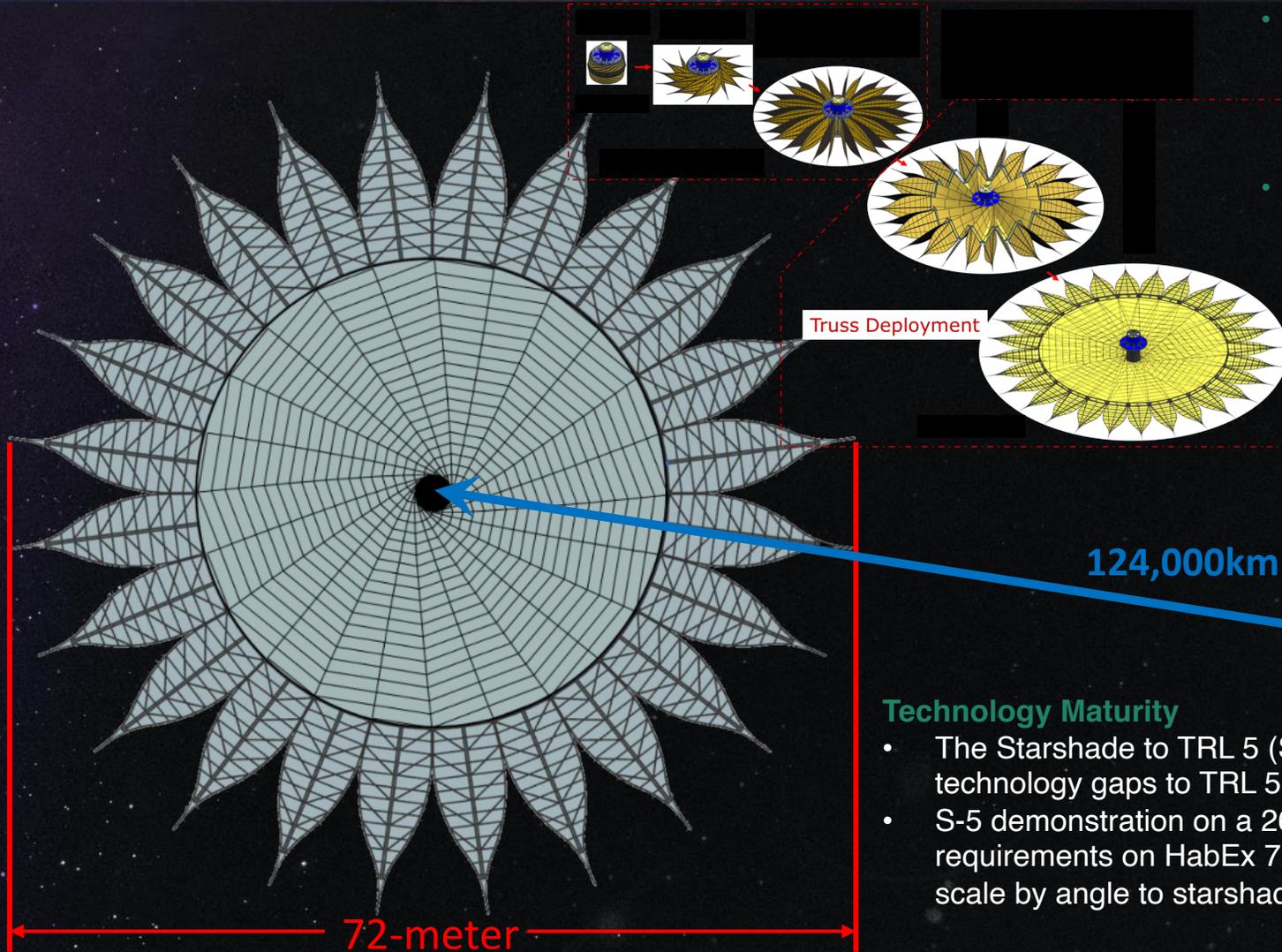


Habitable Exoplanet Imaging Mission	
Mission Duration:	5 years
Orbit:	Earth-Sun L2 Halo orbit
Aperture:	4-meter unobscured
Telescope Architecture:	off-axis, Three Mirror Anastigmat (TMA)
Primary Mirror:	f-number: f/2.5 construction: monolith reflective coating: Al+MgF2
Wavelengths:	115nm – 2500nm (UV, Vis, NIR)
Instruments:	- Coronagraph - Starshade Camera + Starshade Occulter - High-Resolution UV Spectrograph - Multi-purpose, Wide-field Camera & Spectrograph
Starshade	72-meter diameter starshade occulter
Attitude Control System (ACS):	- Fine-Guiding Sensor Instrument - biprop thrusters (slewing) - microthrusters (pointing)
Formation Flying Control System:	- position sensor - local communications
Communications:	phased-array antenna
Serviceability:	- instruments (4) - thrusters - avionics - communications - refueling: telescope + starshade

WED 5:30 pm, 246.38. HabEx Optical Telescope Concepts: Design and Performance Analysis [H. P. Stahl](#)

The 4m monolithic primary TRL of 4 is enabled by microthrusters and the SLS lift capacity





• Propulsion (Occulter)

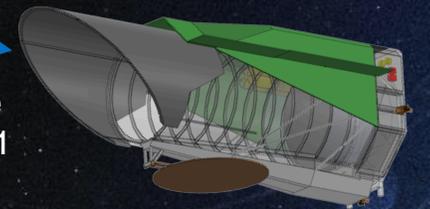
- Solar Electric Propulsion (SEP) with Hermes Hall effect thrusters for slewing (repositioning)
- Biprop thrusters for attitude control
- >100 targets / 5yrs

• Observing

- $\leq 10^{-10}$ Suppression
- 40 – 83 degree sun-angles
- 450 – 1000nm wavelengths at **nominal** separation
 - IWA = 62 mas
 - IFS, R = 140
- 150– 300nm wavelengths at farther distance
 - IWA = 28 mas
 - Grism, R = 7
- 1000 – 1800nm at closer distance
 - IWA = 111 mas
 - Slit spectrograph, R = 140
- OWA = 1.9 arcsec

Technology Maturity

- The Starshade to TRL 5 (S-5) project is maturing 5 starshade technology gaps to TRL 5: 3 by the end of 2019 and 2 by 2021
- S-5 demonstration on a 26 m starshade achieves HabEx requirements on HabEx 72 m starshade because requirements scale by angle to starshade.





Workhorse Camera Instrument	
Purpose:	Multi-purpose, wide-field imaging camera and spectrograph for general astrophysics
Waveband:	<ul style="list-style-type: none"> • UV: 150nm – 400nm • Vis: 400nm – 950nm • NIR: 950nm - 1800nm (2500nm goal)
Telescope Diffraction Limit:	400nm
Field-of-view:	3 arcmin x 3 arcmin
Spectral Resolution:	R = 2000
Detector:	<ul style="list-style-type: none"> • UV/Vis: 3x3 CCD203 12288x12288 pixels • NIR: 2x2 H4RG10 8192x8192 pixels
Multi-Object Spectroscopy (MOS) capable	Micro-shutter array, 2x2 array 200x100 um 171x365 apertures

UV Spectrograph Instrument	
Purpose:	High resolution, UV spectroscopy for general astrophysics
Waveband:	115nm – 360nm (20 bands)
• Spectroscopy:	
Telescope Diffraction Limit:	400nm
Field-of-view:	3 arcmin x 3 arcmin
Spectral Resolution:	R = 500 – 60,000 (band dependent)
Detector	<ul style="list-style-type: none"> • 6x6 MCP array, 100mm sq each • 60000x60000 pixels
Multi-Object Spectroscopy (MOS) capable	Micro-shutter array, 2x2 array 200x100 um 171x365 apertures

- UV requirements are met by the state of the art.
- UV Performance can be enhanced by advancements in UV coatings and detectors